

Transesophageal Dobutamine Stress Echocardiography in the Evaluation of Coronary Artery Disease

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Objectives. The goal of this study was to determine the feasibility, safety, sensitivity and specificity of transesophageal dobutamine stress echocardiography for the detection of coronary artery disease.

Background. Dobutamine stress echocardiography has been shown to be an extremely sensitive and specific noninvasive technique for the detection of myocardial ischemia. However, inadequate transthoracic images preclude the use of dobutamine stress echocardiography in a small but significant group of patients. Transesophageal echocardiography provides better resolution than that obtained with routine transthoracic imaging.

Methods. Patients scheduled for routine cardiac catheterization underwent transesophageal dobutamine stress echocardiography. All patients underwent coronary arteriography within 48 h of the study, and lesion severity was determined by quantitative coronary angiography. Significant coronary obstruction was defined as stenosis >50%.

Results. Fifty-one male patients were enrolled in the study; six were excluded for technical reasons. There were no adverse

outcomes or complications. Of 27 patients with significant coronary artery disease, 22 had positive study results (sensitivity 82%). Of 13 patients without significant obstructive coronary disease, 1 had a false positive study result (specificity 93%). In patients with a minimal lumen diameter <1.25 mm, sensitivity was >80%, and in patients with a minimal lumen diameter >1.5 mm, sensitivity was <70%, suggesting that lesions with a minimal lumen diameter <1.25 mm are more likely to be physiologically significant.

Conclusions. Transesophageal dobutamine stress echocardiography is a feasible, safe and accurate technique for the detection of myocardial ischemia. There are inherent limitations to this technique in that transesophageal echocardiography must be performed. Transesophageal dobutamine stress echocardiography may allow extension of dobutamine stress testing to patients with inadequate transthoracic echocardiographic imaging and may provide an opportunity for further research applications.

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Dobutamine stress testing in combination with two-dimensional transthoracic echocardiographic imaging provides accurate diagnostic and prognostic information in patients at risk for coronary artery disease (1-5). In patients with significant coronary artery disease, graded infusion of dobutamine results in the controlled development of myocardial ischemia. The echocardiographic equivalent of myocardial ischemia is a new or worsening wall motion abnormality (6-8). The sensitivity and specificity of transthoracic dobutamine stress testing equals other forms of noninvasive evaluation of coronary artery disease (9-11). Dobutamine stress echocardiography has been shown to be accurate in risk stratification after myocar-

dial infarction (12-14), preoperative risk assessment (15-17) and identification of viable and hibernating myocardium (18-20).

In a small but significant number of patients, transthoracic echocardiographic images are not of sufficient quality to allow accurate delineation of endocardial boundaries. This is most commonly seen in obese patients or in patients with obstructive pulmonary disease or chest wall deformities. In these patients, dobutamine stress testing using transthoracic imaging is inadequate. Transesophageal echocardiography can overcome some of the limitations inherent in transthoracic echocardiography (21,22). Improved visualization of epicardial and endocardial borders is one of the major advantages of transesophageal echocardiography. As a result, transesophageal echocardiography is used to monitor patients at high risk for intraoperative ischemia (6-8,23,24).

This study attempted to evaluate the potential role of transesophageal echocardiography during graded dobutamine infusion in screening patients for obstructive coronary artery disease. We performed a prospective study to determine the safety, feasibility, sensitivity and specificity of transesophageal dobutamine stress echocardiography for the detection of coronary artery disease.

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Methods

Study patients. Subjects were recruited from patients undergoing elective cardiac catheterization for evaluation of chest pain at the Atlanta Veterans Affairs Medical Center. Exclusion criteria included 1) history of myocardial infarction within 1 month; 2) history of ventricular tachycardia or ventricular fibrillation; 3) current atrial fibrillation, atrial flutter or multifocal atrial tachycardia; 4) clinical evidence of significant valvular heart disease by echocardiography; 5) unstable angina; and 6) history or evidence of mediastinal, pulmonary or esophageal mass. All patients underwent cardiac catheterization within 48 h of the study. In all patients antianginal medications were continued during the day of the study. All patients gave informed written consent for this study. The study protocol was approved by the Human Investigations Committee of Emory University School of Medicine.

Study protocol. Transesophageal imaging was performed at baseline and during dobutamine infusion. All patients were studied in the left lateral decubitus position. Before passing the transesophageal probe, 1 to 3 mg of intravenous midazolam was administered for sedation, and 10% lidocaine spray was used for topical anesthetic. Heart rate, blood pressure and pulse oximetry were continuously monitored during the procedure. A 12-lead electrocardiogram (ECG) was obtained during each stage of the protocol. All echocardiographic studies were performed using a Hewlett-Packard Sonos 1500 and a 5-MHz biplane transesophageal probe. At baseline, biplane images were obtained in the midesophageal and transgastric views. During dobutamine infusion, the transesophageal probe was left in the transgastric position to monitor for the development of regional wall motion abnormalities. After baseline images were obtained, dobutamine infusion was begun at 10 $\mu\text{g/kg}$ body weight per min. The infusion was increased in increments of 10 $\mu\text{g/kg}$ per min at 3-min intervals up to a maximal infusion rate of 40 $\mu\text{g/kg}$ per min. If 85% of the predicted maximal heart rate was not attained at 40 $\mu\text{g/kg}$ per min, then 0.6 mg of atropine was given intravenously. Transgastric short- and long-axis images at each level of dobutamine infusion were obtained 2 min into each stage. A 12-lead ECG was also obtained 2 min into each stage. Criteria for termination of infusion were attainment of 85% of the predicted maximal heart rate, development of new or worsened wall motion abnormality, angina, arrhythmia, ECG changes consistent with ischemia or intolerance of the transesophageal probe.

At peak dose, images were obtained in the transgastric view, and the probe was then withdrawn into the esophagus for the lower esophageal views. Baseline and peak images were digitized in a quad screen continuous loop format for later review and analysis.

Analysis of echocardiograms. All echocardiographic studies were interpreted in blinded manner by two experienced echocardiographers (S.F., W.R.T.) using a modified version of a 16-segment model previously described (25). The development of a new or worsened regional wall motion abnormality

was considered to be a positive echocardiographic result. Any conflicts between the two reviewers' interpretations were settled by discussion.

Quantitative coronary angiography. Coronary angiography was performed in all patients utilizing the Judkins or multipurpose technique with either 6F or 7F catheters. Quantitative coronary angiography was performed as previously described (26). Significant coronary artery disease was defined as $\geq 50\%$ stenosis of a major epicardial coronary artery or a major branch vessel. In patients who had coronary artery bypass grafts, percent stenosis of saphenous vein or internal mammary grafts was determined in the same manner.

Results

Study group. Transesophageal dobutamine stress echocardiography was attempted in 51 male patients. Two patients (4%) did not tolerate intubation with the transesophageal probe sufficiently to allow continuous imaging; therefore, the remaining 49 patients comprised the study group ($61.6 \pm 1.2\%$ [mean \pm SEM]). Twenty-four patients (49%) had one-vessel disease; 10 (20%) had two-vessel disease; none had three-vessel or left main coronary artery disease; and 15 (31%) had nonobstructive coronary disease. Of the 15 patients who had nonobstructive coronary disease, 7 had completely normal coronary anatomy by angiography, and 8 had mild lumen irregularities. Of the entire study group, 20 patients (41%) had a previous history of myocardial infarction and 19 (39%) had undergone revascularization.

All patients were being evaluated for a chest pain syndrome and had either chronic stable angina (40%) or atypical chest pain symptoms (60%). All patients studied had at least one significant risk factor for coronary atherosclerotic heart disease. Using family history, male gender, age >55 years, hypertension, diabetes mellitus, hypercholesterolemia and history of tobacco use as the major risk factors, 32 patients (65%) had one to three cardiac risk factors, and 17 (35%) had more than three cardiac risk factors.

Feasibility. In four studies (8%) the results were considered inadequate for interpretation because of poor image quality either at baseline or during stress imaging. In two patients (4%) the test was terminated before dobutamine infusion because the baseline images were inadequate for interpretation (one patient had a large ventral hernia, the other a documented history of hiatal hernia). In two other patients (4%), baseline images were adequate for interpretation, but images acquired during dobutamine infusion became unacceptable, and these studies were considered incomplete (one patient had a documented history of hiatal hernia, the other a long history of gastroesophageal reflux).

Transesophageal dobutamine stress echocardiography was successful in 45 patients (92%). A total of five patients (10%) were excluded from the final analysis because they did not attain the target heart rate. In five patients, 0.6 mg of atropine was given to increase the chronotropic response to reach maximal heart rate. Of these patients, three did not attain the

target heart rate and were excluded from the final analysis. Two other patients did not attain the target heart rate but were not given atropine at the discretion of the operator and were also excluded. Mean study duration from the time of transesophageal intubation to completion of peak stress imaging was 15.6 ± 0.7 min. For studies with positive results, mean study duration was 14.6 ± 0.9 ; for studies with negative results, mean study duration was 16.3 ± 1.0 ($p < 0.05$).

Safety. No patient experienced a complication or adverse outcome because of esophageal intubation. All ECGs immediately after intubation and before dobutamine infusion had no evidence of ischemia. One patient ($2 \pm 0.038\%$) had a brief period of asymptomatic supraventricular tachycardia at peak dobutamine infusion that responded to cessation of the infusion and a small dose of intravenous beta-adrenergic blocking agent.

Transesophageal dobutamine stress echocardiography. A total of 40 patients (82%) who had adequate images for analysis were included in the final analysis. Mean maximal heart rate was 110 ± 4.8 beats/min in patients with positive transesophageal dobutamine stress echocardiographic results and 132 ± 1.9 beats/min in those with negative results ($p < 0.05$). Mean peak dobutamine dose was 28.3 ± 1.6 $\mu\text{g/kg}$ per min for positive and 31.8 ± 2.1 $\mu\text{g/kg}$ per min for negative echocardiographic results ($p = 0.06$). Representative digitized images from studies with normal and abnormal findings are shown in Figure 1.

Twenty-two of 27 patients with significant coronary artery disease had positive dobutamine echocardiographic results (sensitivity 82%). One of the 13 patients without significant obstructive coronary disease had false positive findings on the dobutamine stress echocardiogram (specificity 93%). Sensitivity of transesophageal dobutamine stress echocardiography for patients with single-vessel versus multivessel disease is shown in Figure 2. For patients with disease in one major coronary artery, sensitivity was 76% (13 of 17) and 90% (9 of 10) for those with two-vessel disease.

We also investigated the relation between lesion severity and a positive echocardiographic result. As lesion severity increased, the sensitivity of transesophageal dobutamine stress echocardiography improved (Fig. 3). Sensitivity was 82% for lesions with stenosis $>50\%$ and 100% for those with stenosis $>80\%$ ($p < 0.005$).

The effect of minimal lumen diameter on sensitivity is depicted in Figure 4. Sensitivity was $>80\%$ for lesions with a minimal lumen diameter <1.25 mm and decreased to $<70\%$ for those with a minimal lumen diameter >1.5 mm ($p < 0.010$). Fifteen of 18 patients with a minimal lumen diameter ≤ 1 mm had positive findings on the transesophageal dobutamine stress echocardiogram (sensitivity 83%). Two of the three patients with a minimal lumen diameter <1 mm and negative findings on the transesophageal dobutamine stress echocardiogram had lesions in the midportion of the diseased vessels (one circumflex and one left anterior descending coronary artery); the third patient had a right coronary artery lesion that supplied an

area with a baseline wall motion abnormality from a previous inferior infarction.

Neither the development of symptoms nor ECG findings during the graded dobutamine infusion were found to be sensitive predictors of significant coronary artery disease. Only three patients in the study group had positive stress ECG results during dobutamine infusion, and two of these experienced their typical chest pain during dobutamine infusion. All three patients had significant obstructive coronary disease of at least one major coronary artery (specificity 100%), and all three had positive findings on the transesophageal dobutamine stress echocardiogram. However, of the 27 patients with significant obstructive coronary artery disease, these were the only positive ECG findings (sensitivity 11%). There were no false positive stress ECG results.

Discussion

Dobutamine stress echocardiography is rapidly becoming the pharmacologic stress imaging technique of choice in many cardiovascular centers. One factor limiting the use of transthoracic dobutamine stress echocardiography in a small but significant number of patients is the ability to obtain adequate images. This is most common in obese patients or those with chronic obstructive pulmonary disease or chest wall deformities. Transesophageal echocardiography has been shown to avoid some of the pitfalls inherent in obtaining images by the transthoracic approach (20,21) and is a sensitive method for the detection of ischemia-induced segmental wall motion abnormalities (7,23,24).

The important new findings in our study are that transesophageal dobutamine stress echocardiography 1) is safe and feasible, 2) is sensitive and specific for noninvasive evaluation of coronary artery disease, and 3) has some potentially significant limitations.

Feasibility and safety. No significant adverse reactions were observed in our study group. The procedure was generally well tolerated by patients, with only 4% of the studies terminated because of patient discomfort. Total time of transesophageal probe insertion was relatively short (15.6 ± 0.7 min). One patient developed an asymptomatic supraventricular tachycardia that resolved on termination of the dobutamine infusion and subsequent administration of a small dose of intravenous beta-blocker. There were no complications associated with insertion of the transesophageal probe.

In a small number of patients (8%), poor echocardiographic images resulted in either termination of the study or the inability to detect regional wall motion abnormalities. This appeared to be related to the presence of a hiatal hernia or related gastroesophageal disease in these patients. Bowles et al. (27) recently reported an association between the presence of hiatal hernias and the inability to obtain adequate transesophageal images. This is presumably due to an abnormal anatomic relationship between the heart and the esophagus.

Sensitivity and specificity. Overall sensitivity for lesion stenosis $>50\%$ was 82%, and overall specificity was 93%. In

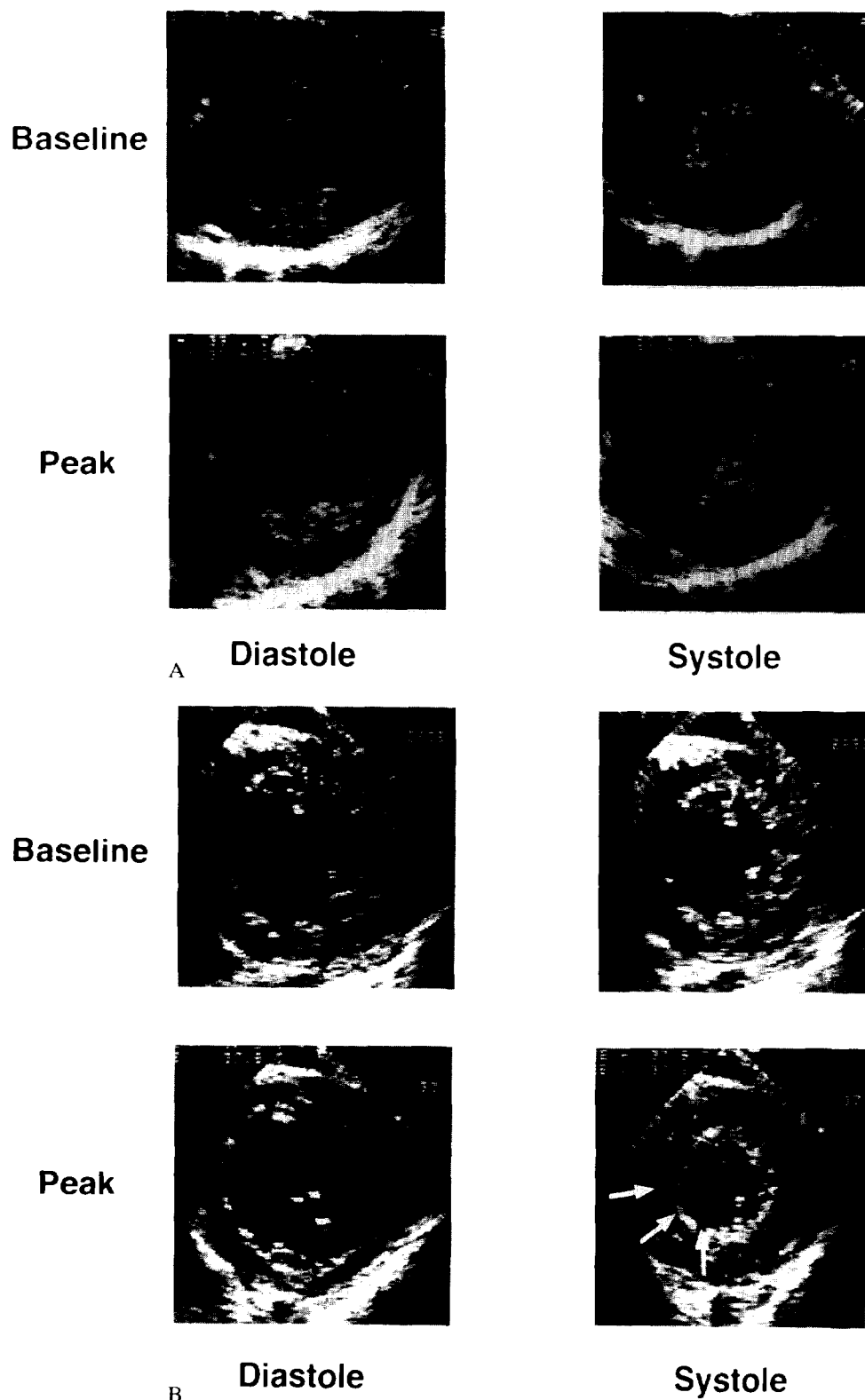


Figure 1. Representative images from studies with normal and abnormal findings. **A**, Example of normal findings in digitized transgastric horizontal images during diastole and systole both at rest and during peak dobutamine infusion. There is no evidence of regional wall motion abnormalities. **B**, Example of abnormal results. **Left**, diastolic images; **bottom right**, peak dobutamine image during systole; **white arrows** indicate an area of dobutamine-induced hypokinesia in the anteroseptal segment.

patients with single-vessel disease, sensitivity was 76%, and specificity was 91%. In patients with double-vessel disease, sensitivity was 90%, and specificity was 91%. Sensitivity of transesophageal dobutamine stress echocardiography appears to be similar to that of transthoracic dobutamine stress echocardiography. Sawada et al. (2) performed transthoracic do-

butamine stress echocardiography in 35 patients with significant obstructive coronary artery disease, defined as a lesion stenosis of at least 50%. Sensitivity and specificity were 89% (31 of 35) and 85% (17 of 20), respectively. Mazeika et al. (3) studied 36 patients by transthoracic echocardiography who had at least one major epicardial coronary artery with a stenosis of

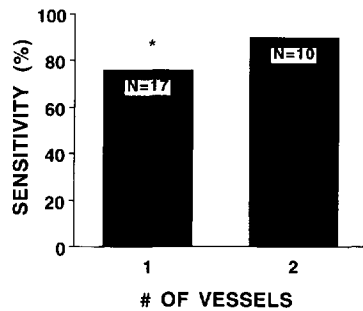


Figure 2. Sensitivity of transesophageal dobutamine stress echocardiography for one- versus two-vessel disease. * $p < 0.010$.

at least 70%, and obtained an overall sensitivity and specificity for detection of significant coronary artery disease of 78% and 93%, respectively. Of 70 patients studied by transthoracic dobutamine stress echocardiography by Cohen et al. (4), 44 of 51 with significant obstructive coronary artery disease had positive findings (sensitivity 86%), and 18 of 19 without significant obstructive coronary artery disease had negative findings (specificity 93%). Overall sensitivity of 82% and specificity of 93% in the present study compares favorably with the results of previous transthoracic studies; however, we did not directly compare transthoracic and transesophageal stress images. In the patients at our institution, up to 30% have inadequate transthoracic echocardiographic endocardial definition.

Of the five patients with obstructive coronary artery disease and negative transesophageal dobutamine stress echocardiographic results, four had single-vessel disease. Two of these patients had diffuse disease involving marginal branches of the circumflex artery, and the lesions were in the midportion of these vessels. The other two patients had lesions involving the midportion of the right coronary artery that supplied previously damaged regions and had baseline wall motion abnormalities. The remaining patient had two-vessel disease with a lesion in the midportion of the left anterior descending coronary artery that supplied the apex and a lesion in the midportion of a marginal branch of the circumflex artery. Therefore, ischemic regions may not have been visualized throughout the

Figure 3. Effect of lesion severity on calculated sensitivity. As lesion severity increased, sensitivity of transesophageal dobutamine stress echocardiography to detect significant lesions increased. * $p < 0.005$ compared with stenosis $>80\%$ by chi-square analysis.

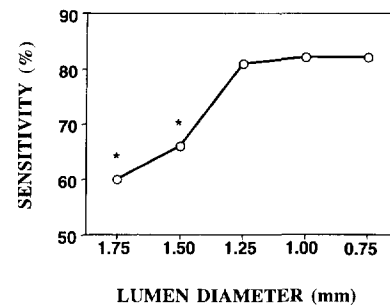
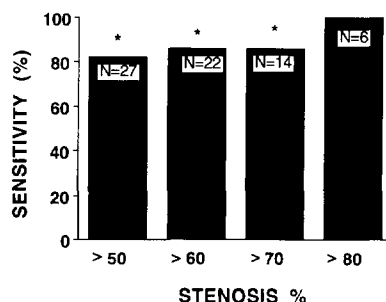


Figure 4. Effect of minimal lumen diameter (mm) on sensitivity. For lesions with minimal lumen diameter <1.25 mm, sensitivity was $>80\%$ compared with lesions with minimal lumen diameter >1.5 mm, for which sensitivity decreased $<70\%$. * $p < 0.010$ compared with minimal lumen diameter <0.75 mm by chi-square analysis.

entire study, but there was no predilection for a particular vascular bed.

Overall specificity of transesophageal dobutamine stress echocardiography was 93%. One of 14 patients with nonobstructive coronary artery disease had false positive study results. This patient had left ventricular hypertrophy and normal coronary anatomy by angiography. At peak dose, the patient developed anteroseptal hypokinesia without ECG evidence of ischemia. The patient had no chest pain or dyspnea, and the test was terminated and the results labeled positive. Subsequent cardiac catheterization revealed no evidence of obstructive coronary disease. Patients with hypertension and myocardial hypertrophy may have signs and symptoms of myocardial ischemia in the absence of obstructive disease of the epicardial coronary arteries. Previous investigators (28) have suggested that this may be related to either microvascular disease or impaired vasodilatory reserve.

Positive ischemic ECG changes during dobutamine infusion were seen in only three patients, all of whom had significant coronary artery disease and positive echocardiographic results. These findings compare favorably with published reports using transthoracic imaging (9,29).

To our knowledge only one other investigator has utilized transesophageal imaging during dobutamine infusion. In a preliminary report, Panza et al. (30) used transesophageal stress dobutamine echocardiography for detection of coronary artery disease. Using 70% obstruction as the definition of significant obstructive disease, their series had a sensitivity and specificity of 88% and 100%, respectively.

Previous studies utilizing other forms of stress transesophageal imaging have demonstrated similar results. Agati et al. (31) combined transesophageal imaging with dipyridamole infusion in 32 patients and obtained an overall sensitivity and specificity for identifying significant obstructive coronary artery disease, defined as lesion stenosis $>70\%$, of 92% and 100%, respectively. Sensitivity of transesophageal dipyridamole stress echocardiography for single-, double- and triple-vessel disease was 67%, 100% and 100%, respectively. High quality images for analysis were obtained in all patients. Lambert et al. (32) performed transesophageal imaging with simultaneous atrial

pacing in 50 patients, all of whom had adequate images. Significant coronary artery disease was defined as >50% lumen diameter narrowing of a major coronary vessel, and their procedure had an overall sensitivity and specificity of 93% and 100%, respectively. For single-, double- and triple-vessel disease, the sensitivity of their test was 85%, 100% and 100%, respectively. When the results of these studies were compared with those in our study group, the overall sensitivity and specificity were favorable. The overall success rate for obtaining adequate images in our group was 88%, which was lower than that reported in previous studies.

Analysis of lesion severity using minimal lesion diameter. Minimal lumen area or diameter obtained by quantitative angiography may be a more physiologic marker for severity of coronary artery lesions than percent diameter stenosis determined by visual estimation (33-35). In the present study, analysis of patients with a minimal lumen diameter <1.25 mm yielded an overall sensitivity >80% but <70% for patients with a minimal lumen diameter >1.5 mm. Segar et al. (36) showed that detection of stenosis in individual coronary arteries is improved in those lesions with a minimal lumen diameter <1 mm (sensitivity 86%), indicating that these lesions are more likely to be physiologically significant. Recently, Baptista et al. (37) reported that in patients with a minimal lumen diameter \leq 1.07 mm, sensitivity of dobutamine stress echocardiography in predicting the physiologic significance of a coronary stenosis was 94%. Therefore, lesions with a minimal lumen diameter <1 mm are likely to be correctly identified using either the transthoracic or transesophageal approach.

Potential limitations of transesophageal dobutamine stress echocardiography. The inherent limitation of this study is the necessity of obtaining a transesophageal echocardiogram. The contraindications of transesophageal echocardiography limit patient selection. Ischemia that is confined to the apex of the left ventricle may be missed by monitoring for segmental wall motion abnormalities from a single transgastric short-axis position (38). Shah et al. (38) studied 94 patients in the intensive care unit or intraoperatively for development of segmental wall motion abnormalities and found that 7 of 20 segmental wall motion abnormalities were visualized only in the longitudinal plane. Therefore, at each stage of dobutamine infusion we utilized the longitudinal long-axis view to increase detection of segmental wall motion abnormalities. However, utilizing the transgastric view of the left ventricle at midcavity continuously during dobutamine infusion does not provide a view of all ventricular segments, and significant lesions located in the mid or distal portion of vessels may not be detected using this approach.

At our institution there is a high prevalence of coronary artery disease, and in such patients there is a high pretest probability of a positive result. In our study group there was a high incidence of previous myocardial infarction and revascularization. All patients with significant coronary artery disease had one- or two-vessel disease, and no patient had three-vessel or left main coronary disease. Similarly, only 7 of the 15 patients who comprised the group described as having nonob-

structive coronary disease had angiographically normal coronary anatomy. This highly selected group of patients with a high prevalence of coronary artery disease may tend to alter the predictive accuracy of a noninvasive screening test such as transesophageal dobutamine stress echocardiography.

Five of our patients did not achieve maximal heart rate during dobutamine infusion, and these studies were considered incomplete. In our protocol, medications were not discontinued 24 h before the study. This may have contributed to the failure to obtain adequate heart rate responses in all of our patients.

Conclusions. Transesophageal dobutamine stress echocardiography as a screening test for detection of coronary artery disease in the general population may be of limited clinical utility. Continuing improvement in echocardiographic imaging systems and the development of intravenous contrast agents that improve endocardial border definition may further reduce the need for transesophageal imaging during stress studies. However, we showed that this test is safe, feasible and sensitive for the detection of significant coronary artery disease and may be useful in a select group of patients. This test may be useful for research purposes only or may become clinically useful when smaller transesophageal probes are developed to allow better patient acceptance.

References

1. Armstrong WF. Stress echocardiography for detection of coronary artery disease. *Circulation* 1991;84 Suppl 1:I-43-9.
2. Sawada SG, Segar DS, Ryan T, et al. Echocardiographic detection of coronary artery disease during dobutamine infusion. *Circulation* 1991;83:1605-14.
3. Mazeika PK, Nadazdin A, Oakley CM. Dobutamine stress echocardiography for detection and assessment of coronary artery disease. *J Am Coll Cardiol* 1992;19:1203-11.
4. Cohen JL, Greene TO, Ottenweller J. Dobutamine digital echocardiography for detecting coronary artery disease. *Am J Cardiol* 1991;67:1311-8.
5. Mertes H, Sawada SG, Ryan T, et al. Symptoms, adverse effects, and complications associated with dobutamine stress echocardiography. *Circulation* 1993;88:15-9.
6. Smith JS, Cahalan MK, Benefiel DJ, et al. Intraoperative detection of myocardial ischemia in high-risk patients: electrocardiography versus two-dimensional transesophageal echocardiography. *Circulation* 1985;72:1015-21.
7. Topol EJ, Weiss JL, Guzman PA, et al. Immediate improvement of dysfunctional myocardial segments after coronary revascularization: detection by intraoperative transesophageal echocardiography. *J Am Coll Cardiol* 1984;4:1123-34.
8. Beaupre PN, Kremer PF, Cahalan MK, Lurz FW, Schiller NB, Hamilton WK. Intraoperative detection of changes in left ventricular segmental wall motion by transesophageal two dimensional echocardiography. *Am Heart J* 1984;107:1021-3.
9. Cohen JL, Ottenweller JE, George AK, Duvvuri S. Comparison of dobutamine and exercise echocardiography for detecting coronary artery disease. *Am J Cardiol* 1993;72:1226-31.
10. Herman SD, LaBresh KA, Santos-Ocampo CD, et al. Comparison of dobutamine and exercise using technetium-99m sestamibi imaging for the evaluation of coronary artery disease. *Am J Cardiol* 1994;73:164-9.
11. Previtali M, Fetiiveau R, Poli A, et al. Comparison of dobutamine stress echocardiography, dipyridamole stress echocardiography and exercise stress testing for diagnosis of coronary artery disease. *Am J Cardiol* 1993;72:865-70.
12. Smart SC, Sawada S, Ryan T, et al. Low-dose dobutamine echocardiography

- detects reversible dysfunction after thrombolytic therapy of acute myocardial infarction. *Circulation* 1993;88:405-15.
13. Berthe C, Pierard LA, Hiernaux M, et al. Predicting the extent and location of coronary artery disease in acute myocardial infarction by echocardiography during dobutamine infusion. *Am J Cardiol* 1986;58:1167-72.
14. Mannering D, Cripps T, Leech G, et al. Dobutamine stress test as an alternative to exercise testing after acute myocardial infarction. *Br Heart J* 1986;59:521-6.
15. Poldermans D, Fioretti PM, Forster T, et al. Dobutamine stress echocardiography for assessment of perioperative cardiac risk in patients undergoing major vascular surgery. *Circulation* 1993;87:1506-12.
16. Davila-Roman VG, Waggoner AD, Sicard GA, Geltman EM, Schechtman KB, Perez JE. Dobutamine stress echocardiography predicts surgical outcome in patients with an aortic aneurysm and peripheral vascular disease. *J Am Coll Cardiol* 1993;21:957-63.
17. Lane RT, Sawada SG, Segar DS, et al. Dobutamine stress echocardiography for assessment of cardiac risk before non cardiac surgery. *Am J Cardiol* 1991;68:976-7.
18. Cigarroa CG, deFilippi CR, Brickner ME, Alvarez LG, Wait MA, Grayburn PA. Dobutamine stress echocardiography identifies hibernating myocardium and predicts recovery of left ventricular function after coronary revascularization. *Circulation* 1993;88:430-6.
19. Barilla F, Gheorghade M, Alam M, Khaja F, Goldstein S. Low-dose dobutamine in patients with acute myocardial infarction identifies viable but not contractile myocardium and predicts the magnitude in response to coronary revascularization. *Am Heart J* 1991;122:1522-31.
20. Akosah KO, Porter TR, Simon R, Funai JT, Minisi AJ, Mohanty PK. Ischemia-induced regional wall motion abnormality is improved after coronary angioplasty: demonstration by dobutamine stress echocardiography. *J Am Coll Cardiol* 1993;21:584-9.
21. Seward JB, Khanderia BK, Oh JK, et al. Transesophageal echocardiography: technique, anatomic correlations, implementation, and clinical applications. *Mayo Clin Proc* 1988;63:649-80.
22. Fisher EA, Stahl JA, Budd JH, Goldman ME. Transesophageal echocardiography: procedures and clinical application. *J Am Coll Cardiol* 1991;18:1333-48.
23. Abel MD, Nishimura RA, Callahan MJ, Rehder K, Ilstrup DM, Tajik AJ. Evaluation of intraoperative transesophageal two dimensional echocardiography. *Anesthesiology* 1987;66:64-8.
24. Gewertz BL, Kremser PC, Zarins CK, et al. Transesophageal echocardiographic monitoring of myocardial ischemia during vascular surgery. *J Vasc Surg* 1987;5:607-13.
25. Bourdillon PD, Broderick TM, Sawada SG, et al. Regional wall motion index for infarct and noninfarct regions after reperfusion in acute myocardial infarction: comparison with global wall motion index. *J Am Soc Echocardiogr* 1989;2:398-407.
26. Klein JL, Manoukian SV, Vogel RA, et al. Computerized quantitative arteriography: performance standards and edge detection [abstract]. *Circulation* 1992;86 Suppl I:I-121.
27. Bowles MH, Lipman RE. Hiatal hernia: the "X" factor in transesophageal echocardiography. *J Am Soc Echocardiogr* 1993;6:631-3.
28. Treasure CB, Klein JL, Vita JA, et al. Hypertension and left ventricular hypertrophy are associated with impaired endothelium-mediated relaxation in human coronary resistance vessels. *Circulation* 1993;87:86-93.
29. Marcovitz PA, Armstrong WF. Accuracy of dobutamine stress echocardiography in detecting coronary artery disease. *Am J Cardiol* 1992;69:1269-73.
30. Panza JA, Laurienzo JM, Quyyumi AA, Cannon III RO. Transesophageal dobutamine stress echocardiography for evaluation of coronary artery disease [abstract]. *Circulation* 1993;88 Suppl I:I-404.
31. Agati L, Renzi M, Sciomer S, et al. Transesophageal dipyridamole echocardiography for diagnosis of coronary artery disease. *J Am Coll Cardiol* 1992;19:765-70.
32. Lambert H, Kreis A, Trumper H, Hanrath P. Simultaneous transesophageal atrial pacing and transesophageal two-dimensional echocardiography: a new method of stress echocardiography. *J Am Coll Cardiol* 1990;16:1143-53.
33. Harrison DG, White CW, Hiratzka LF, et al. The value of lesion cross-sectional area determined by quantitative coronary angiography in assessing the physiologic significance of proximal left anterior descending coronary arterial stenoses. *Circulation* 1984;69:1111-9.
34. White CW, Wright CB, Doty DB, et al. Does visual interpretation of the coronary arteriogram predict the physiologic importance of a coronary stenosis? *N Engl J Med* 1984;310:819-24.
35. Wilson RF, Marcus ML, White CW. Prediction of the physiologic significance of coronary arterial lesions by quantitative lesion geometry in patients with limited coronary artery disease. *Circulation* 1987;75:723-32.
36. Segar DS, Brown SE, Sawada SG, Ryan T, Feigenbaum H. Dobutamine stress echocardiography: correlation with coronary lesion severity as determined by quantitative angiography. *J Am Coll Cardiol* 1992;19:1197-202.
37. Baptista J, Arnes MR, Roelandt JR, et al. Quantitative coronary angiography in the estimation of the functional significance of coronary stenosis: correlations with dobutamine-atropine stress test. *J Am Coll Cardiol* 1994;23:1434-9.
38. Shah PM, Kyo S, Matsumura M, et al. Utility of biplane transesophageal echocardiography in left ventricular wall motion analysis. *J Cardiothorac Vasc Anesth* 1991;5:316-9.